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MINIMAL SLEEP TO MAINTAIN PERFORMANCE: SEARCH FOR SLEEP QUANTUM IN SUSTAINED OPERATIONS

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EXECUTIVE SUMMARY

In many civilian and military occupations, personnel are required to work on a job until it is completed, even if such requirements demand continuous work for a period longer than 24 hours and/or irregular work hours. One of the consequences of working prolonged hours and/or working under irregular schedules is that sleep becomes too disrupted and too short to allow the worker to recuperate from daily fatigue. The disruption of sleep results in the worker's reduced productivity and increased risks of error or injury at work sites. In this paper, applications of sleep management is proposed to minimize degradation in work performance and to improve job safety. The basic knowledge of sleep management is discussed in detail, supplementing a sleep management guideline previously published (Naitoh, Englund and Ryman, 1986). Some of the key questions of sleep management are to determine minimal sleep duration, to evaluate impact of time of day when sleep is taken on recuperative power of sleep, and to measure individual differences in sleep habits. This paper focuses on the question of minimal sleep duration which is necessary to maintain an acceptable level of performance, i.e., "sleep quantum" in sustained operations. The sleep quantum is found to be about 5 hours (4.5-5.5 hours) per 24 hours, corresponding roughly to the core sleep designated by Horne (1988). There are several approaches to obtain the sleep quantum under the around-the-clock work environments of sustained operations. Some are efficient but impractical in sustained operations, such as sleeping continuously for 5 hours during the middle of operations. Others seem to result in less efficient sleep but highly flexible regarding work scheduling, such as ultrashort sleep. In this paper, ultrashort sleep is discussed in terms of its operational advantages and disadvantages. The major advantage of ultrashort sleep is its flexibility. The major disadvantage of ultrashort sleep is its inefficiency, but adaptation to lifestyle necessitating ultrashort sleep (such as yachtsmen engaged in solo transatlantic racing), is quite feasible with resultant improvement of ultrashort sleep efficiency. The future roles of sleep managers were suggested with respect to developments of a technical database and of creating job performance models over ultrashort sleep.

[illegible] Sleep, Optimal Sleep, Prophylactic Sleep, Sleep [illegible] model, Sleep inertia, Sleep Management, Sleep [illegible], [illegible] operations, Ultrashort Sleep [illegible]

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1. SLEEP QUANTUM

The purpose of this paper is to review some of the current research findings which have contributed to determining the minimal amount of sleep needed to maintain a high level of task performance for days, weeks, and even months.

The least amount of sleep, "sleep quantum," which is necessary for efficiently doing a day's work, shows large differences between individuals (Kripke, 1979; Webb, 1985; White, 1975) and, also, varies considerably within each individual. However, the results of acute partial sleep deprivation studies by Wilkinson (1970), Wilkinson, Edwards and Haines (1966), and Haslam (1982) indicate that sleep necessary to prevent performance impairment of vigilance tasks is 4 or more hours of sleep daily. The results of chronic partial sleep deprivation studies have shown similarly that 4.5-5.5 hours of sleep per day are necessary if one wishes to cause no major undesirable behavioral consequences for up to 8 months (Friedmann, Globus, Huntley, Mullaney, Naitoh and Johnson, 1977; Webb and Agnew, 1974).

What is currently believed to be true is that the 4.5-5.5 hours of sleep should be taken continuously (not be fragmented) in order to benefit from maximal recuperation (Bonnet, 1986; Downey & Bonnet,1987; Levine, Roehrs, Stepanski, Zorick, & Roth, 1987; Magee, Harsh & Badia, 1987). This Continuity Theory of Sleep (see Bonnet, 1985, 1986) implies that a sleep "quantum," the smallest fundamental quantity of sleep, is an uninterrupted 4.5-5.5 hours of sleep.

A search of the literature on sleep quantum reveals, however, field observations which show that short sleep of much less than 4.5-5.5 hours, for example, as short as a few tens of minutes, would help recuperate from fatigue and reduce sleepiness (Stampi, 1985a, 1985b, 1988, 1989). Stampi's field observations are supported by laboratory studies reporting benefits over task performance with even a very short length naps (Dinges, 1983, 1989; Dinges, Orne, & Orne, 1985; Dinges, Orne, Orne & Whitehouse, 1986; Haslam, 1982; Naitoh, 1981). In fact, very short naps are often observed in daily routines. Stossel (1970) reported that about one-fourth of the fourth year medical students napped three minutes or longer during the one-hour lecture starting at 8:30 AM. During a particularly dull lecture, over half of the students napped. Wedderburn (1987) reported on short naps, some

lasting only 5 minutes, were taken by shift workers at work sites. He suspected some qualitative difference in these urgent short naps from a much longer sleep usually taken on a bed. Recent studies, primarily focused on modeling the effects of sleep apnea on performance, mood and sleep, suggest that a fragmented nocturnal sleep consisting of many short sleep episodes, ranging from 4 minutes to 2.5 hours, can offer as much recuperation as expected from much longer, continuous sleep (Bonnet, 1986; Magee, Harsh and Badia, 1987). These observations and studies indicate that sleep quantum could be of a magnitude of tens of minutes, not of 4.5-5.5 hours in duration.

2. CORE VS. OPTIONAL SLEEP

In determining relationship between a minimal sleep and an acceptable level of job performance, sleep stages (Rechtschaffen & Kales, 1968) have often been discussed. Each of the sleep stages, such as stage 2, Rapid Eye Movements (REM) sleep, or the combined sleep stages of slow wave sleep (SWS), could play significantly different roles in determining the amount of performance recuperation. Then, an appraisal of sleep quantum would become very complex, because the degree of recuperation after sleep is no longer a matter of sleep duration but the stages of sleep as well.

Fortunately, the duration of each sleep stage, especially of SWS or REM sleep, appears to be unrelated to recuperation and performance maintenance (Lubin, Moses, Johnson & Naitoh, 1974; Johnson, Naitoh, Moses & Lubin, 1974). Lumley, Roehrs, Zorick, Lamphere and Roth (1986) studied the effectiveness of a morning nap (starting at 09:00) of 0, 15, 30, 60 or 120 minutes in neutralizing increased sleepiness due to one night of total sleep deprivation prior to the nap. Changes in alertness were measured by the Multiple SLeep Latency Test (MSLT). They found that napping had alerting effects which were strongly related to the duration of the nap (reaching it highest level with a 60 minute nap), and only weakly related to the sleep stage composition. The sleep quantum is simply measured by time, and not by sleep stages or any other transient events which were observed during sleep. In discussion of a minimal sleep, little reason exists for examining sleep stages.

In discussing sleep duration, Horne (1988; pp. 180-217) has offered a cogent argument for partitioning sleep into two kinds: core vs. optional

sleep. Core sleep is defined as "the first three sleep cycles - the initial 4-5 hours of sleep. (P. 180)" which is necessary for humans to function properly. Optional sleep is the remaining sleep which can be eliminated without dire consequence. Horn's estimate of core sleep matches well with an estimate of the sleep quantum (4.5-5.5 hours) previously mentioned in this paper.

3. CAPTURING CORE SLEEP

There are five ways to capture core sleep, i.e., to satisfy a minimal sleep demand centering around 5 hours a day. They are:

1. To sleep for 5 unbroken hours,
2. To adopt "anchor" sleep,
3. To take "prophylactic" sleep,
4. To have longish (from 1 to 4 hour) naps, and
5. To take "ultrashort" sleep.

3.1 CONTINUOUS 5 HOUR SLEEP

The best way to capture the sleep quantum is to sleep continuously for five hours. Ordinarily, this is a sleep pattern practiced by almost everyone. However, under certain job environments which demand sustained work, a period of 5 uninterrupted luxurious sleep hours cannot be set aside as it conflicts with work schedules (Angus and Heslegrave, 1985; Dinges et al., 1986; Englund, Ryman, Naitoh and Hodgdon, 1985; Mullaney, Kripke, Fleck and Johnson, 1983; Naitoh and Angus, 1989).

3.2. ANCHOR SLEEP

The anchor sleep was introduced by Minors and Waterhouse (1981). They have divided an 8-hour sleep into two 4-hour sleep periods. One of the 4-hour sleep periods was taken at the same time each day (i.e., anchored to a local time). The fixed time should be selected to correspond to a time period that is both suitable for sleep after working days and socially acceptable during days off. For example, Minors and Waterhouse picked up anchor sleep at 0800-1200 for night shift workers sleep after work. During days off, they would sleep during the same time period of 0800-1200, leaving the entire afternoon available for social events...a socially acceptable schedule. The second 4-hour sleep period could be taken at irregular times.

Minors and Waterhouse have observed that, as long as one 4-hour sleep period was anchored to a fixed time of day, the circadian rhythms became stabilized within a few days with periods indistinguishable from 24 hours. In terms of capturing core sleep, anchor sleep offers a degree of scheduling flexibility. Instead of finding a time spot which allows 5 continuous hours for capturing core sleep, only 4 hours of sleep must be scheduled to be continuous and occur at a fixed time of day. However, demands of some work schedules may not permit workers to have the luxury of sleeping for 4 unbroken hours during the fixed time period.

3.3. PROPHYLACTIC SLEEP

Dinges and others (Dinges, 1983; Dinges, et al., 1986; see Naitoh and Angus, 1989) proposed napping in anticipation of sleep loss (i.e., prophylactic napping), or sleeping longer than normal hours so as to "store" sleep. The idea of storing sleep by sleeping longer than usual before the start of a long work period is attractive. However, independent confirmation that a significant amount of sleep can be stored is not yet available.

3.4. LONGISH NAPPING

A more traditional way of getting some sleep during field work is to sleep whenever possible. In sustained operation research, 1 to 4 hour naps were interjected during lulls in the work or whenever possible to find that these longish naps were long enough to partially satisfy the need for core sleep (Angus and Heslegrave, 1985; Englund, Ryman, Naitoh, and Hodgdon, 1985; Haslam, 1982; Mullaney, et al., 1983; Webb, 1985). However, even a 1-hour nap may turn out to be too long to be taken in some work environments of sustained operations.

3.5. ULTRASHORT SLEEP

A view that sleep must be continuous to be efficient and recuperative, Continuity Theory of Sleep, has been popular. Clinical observations of disrupted sleep among sleep disordered patients often strengthened the validity of this view. It is believed that the more fragmented a sleep period is (i.e., the shorter the duration of each sleep episode), the more diminished its refreshing power.

However, in the remainder of this paper, the evidence will be offered to show a need to revise a concept of "continuity" downward from 5 hours to a few tens of minutes. Then, the differences between "fragmented sleep" and "continuous sleep" will blur, as the time requirement for a sleep to be continuous becomes less and less.

4. APPRAISAL OF RECUPERATIVE POWER OF ULTRASHORT SLEEP

The recuperative powers of repeated ultrashort sleeps in maintaining performance efficiency has been brought into sharp focus by Stampi's dramatic field observations of sleep patterns of yachtsmen during solo, long distance yacht races (1985a, 1985b, 1988, 1989). Taking as many ultrashort sleeps as necessary to obviate the need to sleep continuously for 5 hours or longer was shown to be possible, given that there was opportunity to adapt to the life under ultrashort sleep.

Stampi's field research was not the first to reveal that short sleep, or napping, were able to replace the major daily sleep period of 8 continuous hours. There are three kinds of research lines, each of which was initially designed to answer some specific questions unrelated to usefulness of short sleep in capturing core sleep, but demonstrated also that many periods of short sleep can capture core sleep. The researches are on:

1. Fragmented Sleep
2. Sleep Apnea Model, and
3. Day (e.g., a 90 minute day).

4.1. FRAGMENTED SLEEP

Husband (1935) tested one subject who slept 8 hours per night for one month, then 6 hours per night in two sleep episodes, one sleep period at 23:00 to 02:00 and another sleep period at 05:00 to 08:00 during the second month. The time period between two sleep episodes was spent in various activities. Husband used tests of scholastic aptitude, intelligence, and psychomotor skills to determine if interrupted sleep caused mental deterioration as compared with continuous sleep. No consistent degradation of performance was observed due to interrupted sleep during or after experimentation of one month. Hartley (1974) showed that a group of subjects who had three 80-minute naps (at 23:10, 05:30 and 12:25 per day) over 4 consecutive days was poorer in task performance than the control subjects who slept

8 continuous hours, but a higher level of performance was produced than by another group of subjects who slept 4 continuous hours between 0100-0500.

4.2. SLEEP APNEA MODEL

Patients with sleep apnea experience extremely disrupted sleep marked with frequent arousals. In order to model behavioral consequences of severe sleep apneics, Bonnet (1985, 1986) conducted experiments with young, healthy, normal sleepers. In his 1986 paper, subjects experienced four kinds of sleep disruptions over two consecutive nights. The four disruption conditions were: (1) brief awakening (as defined by ability to make a verbal report of sleep/wake status or to solve an addition problem) after 1 minute of accumulated sleep, (2) brief awakening after each 10 minutes of accumulated sleep, (3) the same after 2.5 hours of accumulated sleep, and (4) no sleep. In the morning, the subjects were given addition, vigilance, sleep latency and other tests immediately after their awakening. The results showed that, after two nights of disrupted sleep, "periods of uninterrupted sleep in excess of 10 minutes are required for sleep to be restorative." That is, the sleep quantum is neither 1 minute nor 4.5-5.5 hours, but perhaps about 10 plus some minutes. However, there are significant differences in sleep stages between the 1-minute sleep and the 10-minute sleep: the 1-minute sleep had virtually no SWS and REM sleep, whereas the 10-minute sleep contained more than one half of SWS and REM sleep time in comparison with the baseline sleep. Thus, the restorative power of sleep of a 10 minute nap may have to be attributed also to SWS and REM sleep, in addition to duration of sleep.

Downey and Bonnet (1987) included analyses of performance of 5 subjects who did a random two-digit/two-number addition problem given immediately upon awakening from two consecutive nights of disrupted sleep. They found that as early as night 1, awakening subjects every 1 or 10 minutes caused verbal response to slow down. During night 2, the 1 minute disruption continued to cause additional marked slowing in verbal response to the addition task. "By night 2, response latencies on the average were 7 times control values in the 1-minute condition, remained at 4 times control in the 10-minute condition, and nearly 2.5 times control in the 2.5 hours condition (p.361)." Since the duration of sleep stages were poor predictors of performance, Downey and Bonnet felt that "the data were best explained by

sleep continuity theory, which posits that a period of at least 10 minutes of uninterrupted sleep is required for restoration to take place."

Magee, et al. (1987) conducted a study on the extent of voluntary control of respiration during sleep. During a sleep-disrupted night, young, healthy, University students would take a deep breath to a tone presented every 1 or 4 minutes. Magee et al. measured effects of one disrupted night on sleepiness. They found that the subjects whose sleep was disrupted every minute lost almost all SWS and one half of REM sleep, and slept only about 6 out of 8 hours of bed time. The 4 minute disruption group did not differ from the control non-interrupted sleep group in terms of sleepiness. The results of this study by Magee et al. could be interpreted to show that the sleep quantum could be as short as 4 min, instead of 10 plus some minutes as implied by Bonnet (1986).

4.3 SHORT DAY

Most sleep studies have been conducted under the constraint of a day having 24 hours; each day consisting of one sleep/wake cycle of 8 hours/16 hours. However, a few studies examine much shorter, artificial days (e.g., 90 minute "day") with results which appear to contribute to our understanding of sleep quantum.

Weitzman, Nogeire, Perlow, Fukushima, Sassin, McGregor, Gallagher and Hellman, (1974) studied the effects of a 3 hour "day" of a sleep/wake schedule of 60-minutes/120 minutes over 10 days. Total bed time under this sleep/wake schedule was 8 hours/24 hours. The polygraphic sleep records showed that the subjects slept an average of 4 hours/24 hours during the 10 day study. Sleep efficiency, as calculated by dividing the sum of stages 2, 3, 4 and REM (i.e., total sleep time) by total bed time was 50.9%. No task performance data were collected in this study.

Carskadon and Dement (1975, 1977) studied a "90 minute day." A sleep/ wake schedule was 30 minutes/60 minutes up to 6 (24 hour) days. The subjects could sleep up to 8 hours in 16 sleep episodes, each 30 minutes long. On average, the subjects were able to sleep less than 4 hours per 24 hours across 6 days. Sleep efficiency was 47.6%. No task performance data were collected. Carskadon and Dement noticed that sleepiness increased significantly on the first nap day but decreased to the baseline over the next 4 days, showing a sign of adaptation to altered sleep/wake schedule.

Moses, Hord, Lubin, Johnson and Naitoh (1975) and Lubin, Hord, Tracy and Johnson (1976) examined the sleep/wake schedule of 60 minutes/160 minutes across 40 hours. This represented a total bed time of 6.5 hours/24 hours, but the subjects were able to achieve sleep efficiency of only 47.5%. Unlike other "Short Day" studies, Lubin et al. (1976) used auditory vigilance, addition, word memory tests and Stanford Sleepiness Scale to measure the effects of the sleep/wake schedule which would certainly fragment sleep. The 60 minute nap sessions were beneficial and neutralized performance degradation expected from 40-hour total sleep deprivation.

Mullaney et al. (1983) reported comparisons of performance of three groups under varying sleep/wake schedules. One group was required to work continuously for 42 hours. Another group was required to work continuously, but they were given a 1 hour sleep/rest period every 7 hours (6-and-1). The subjects in this group repeated this sleep/wake cycle 6 times during the 42 hour continuous work period. The third group was required to work for 18 hours, given chance to sleep for the next 6 hours (18-and-6), and then repeated this sequence twice. The authors found that the 6-and-1 group showed superior performance over the other two groups up to the first half of the 42 hour continuous work period. This was attributed to the benefits of the 1 hour naps. The 1 hour naps were not sufficient to maintain performance at the high level as observed among the subjects in the 18-and-6 group after their 6 hour sleep. However, the subjects in the 6-and-1 group performed much better than those subjects who did not sleep at all.

5. ULTRASHORT SLEEP: BENEFITS

The converging lines of evidence, as presented in the previous sections of this paper, seemed to suggest that the duration of each sleep episode must be longer than 4-10 minutes to be recuperative.

In work environments which demand around-the-clock operations with a minimal number of personnel to share job responsibilities, taking a short nap at, or near, the work site is a pragmatic solution to reduce fatigue and sleepiness of long work hours, and highly recommended. Ultrashort sleep of 5, 10 or 20 minutes taken by personnel right at or near the work site may provide a welcome relief for the workers and enhance productivity and safety. Naps on a chair (Nicholson & Stone, 1987) or on a cot placed at a work site refreshes workers and is much easier for management to approve

than a one hour or longer sleep in a room somewhere far away from the work site during the middle of the "work" period.

Ultrashort naps may also prevent occurrence of a rare, but serious, problem of behavioral freezing (Folkard & Condon, 1987), i.e.. instead of responding quickly to an emergency, the individual lapses into temporary immobility).

6. ULTRASHORT SLEEP: PROBLEMS

The benefit of using ultrashort sleep to capture sleep quantum in a prolonged work period needs to be balanced against its two major shortcomings:

1. Sleep inertia and
2. Reduced sleep efficiency.

6.1. SLEEP INERTIA

Immediately after getting up from sleep, irrespective of the hour, one is not at one's best, i.e., sleep inertia (Lubin, et al., 1976). Sleep inertia represents a reduced performance capability during a period after being suddenly awakened from sleep. Pigeau, Heslegrave and Angus (1987) used electroencephalograhic (EEG) indices to find that sleep inertia is characterized by EEGs resembling an early phase of sleep. Balkin and Badia (1988) found that a period of sleep inertia is not a novel state, but merely persistence of "typical" sleepiness. These aftereffects of sleep occur from 1-5 minutes (Dinges, et al., 1985; Webb and Agnew, 1974) to 15 minutes following awakening (Wilkinson and Stratton, 1971). Due to sleep inertia Air Force crews have been prohibited from napping while on the immediate alert or standby (Hartman and Langdon, 1965; Hartman, et al., 1965; Langdon and Hartman, 1961).

Seminara & Shavelson (1969) showed that four test subjects in a simulation study for a NASA five-day lunar mission experienced sleep aftereffects in some tasks persisting for up to 12 minutes, although the largest performance decrements were observed during the first 3 minutes. Naitoh (1981) reported that inadequate short recovery sleep after a prolonged sleep deprivation resulted in more serious and prolonged sleep inertia.

Because of this sleep inertia, workers who are involved in jobs requiring a fully functional, alert mind instantly upon awakening (such as

aviators (Angiboust, 1970) and truck drivers) are not recommended to take any naps during work periods. The cases of infantry soldiers suffering from sleep inertia, as mentioned by Haslam (1982), should be handled differently from the aviators and truck drivers. Infantry soldiers, as well as night nurses and nighttime operators of power generation plants, will have more time for becoming fully awake before appropriate actions are demanded of them. In fact, for some shift work personnel who have less stringent requirements for speed and accuracy of responses, adopting a simple procedure of washing the face with cold water to dispel sleep inertia quickly (Labuc, 1978, 1979a, 1979b) would be highly recommended rather than fighting off waves of sleepiness.

6.2. LOSS OF SLEEP EFFICIENCY

Ultrashort sleep appears to reduce sleep efficiency in comparison with long continuous sleep. Previously, in the discussion of "short day" or non 24 hour day, an average sleep efficiency was estimated to be about 50%. This means, under ultrashort or non 24-hour work/day schedules, we might be given an opportunity to sleep but, on average, we can use one half of that "bed time" for actually sleeping. However, as pointed out by Stampi (1989), sleep efficiency is expected to improve once we have adapted to a new sleep/wake schedule. Hence, the loss of sleep efficiency in ultrashort sleep appears to be lack of opportunity and/or motivation to adapt to the work environments which demand ultrashort sleep. Suggestions have been made either to use quick acting hypnotics to induce sleep, or to train sleepers on techniques of biofeedback and autogenic relaxation for rapid sleep onset and for improving sleep efficiency.

7. SLEEP MANAGEMENT: NEW MANDATE

Despite the two drawbacks in practicing ultrashort sleep at work sites, ultrashort sleep offers the management of sleep a flexible tool in capturing sleep quantum without interferring down military or industry operations. Unfortunately, much of the necessary data on ultrashort sleep are not available.

When should workers be advised to take ultrashort sleep on their work sites? Should they sleep on a chair or a cot placed right at or near the work sites, or should they sleep in a secluded area for maximal sleep

efficiency? How many minutes of ultrashort sleep should be allowed? How long will the recuperative effects of an ultrashort sleep last?

8. THE JOB OF SLEEP MANAGER

While the science of sleep management works towards gaining more information about the recuperative power of ultrashort sleep, sleep managers need to accomplish especially the following two objectives using currently available technical base:

1. To develop a technical database describing the roles of ultrashort sleep in sustained/continuous operations, and
2. To develop a performance model for ultrashort sleep.

8.1. DATABASE FOR ULTRASHORT SLEEP

Figure 1 shows a flow diagram describing the role of sleep management, particularly of ultrashort sleep. The work environments to be discussed in Figure 1 are quite common among military personnel where they are required to work continuously with little or no sleep for a prolonged period of time until the task is completed (Sustained or Continuous Operation, SUSOP/CONOP).

If work is completed in less than 24 hours, there would be no need to invoke counter degradation measures (CDMs) to support individual and group performance. However, if the task requires personnel to work longer than 24 hours continuously and the work begins to interfere with sleep, the sleep manager needs to apply as many CDMs as available to support the work forces. Figure 1 lists five CDMs.

In applying sleep logistics, the first action is to observe whether workers are presently napping. If they are not napping, then the next vital concern is to determine when they ought to start napping. If the workers are found asleep, the vital decision is to determine when they should be awaken.

The decision processes (marked with the large X in Figure 1) on when to begin or end a nap will be based on the technical database which is boxed in, for the sake of emphasis, at the bottom of Figure 1. The technical database for napping and ultrashort sleep still remains incomplete, awaiting more data from future experimentations and field observations.

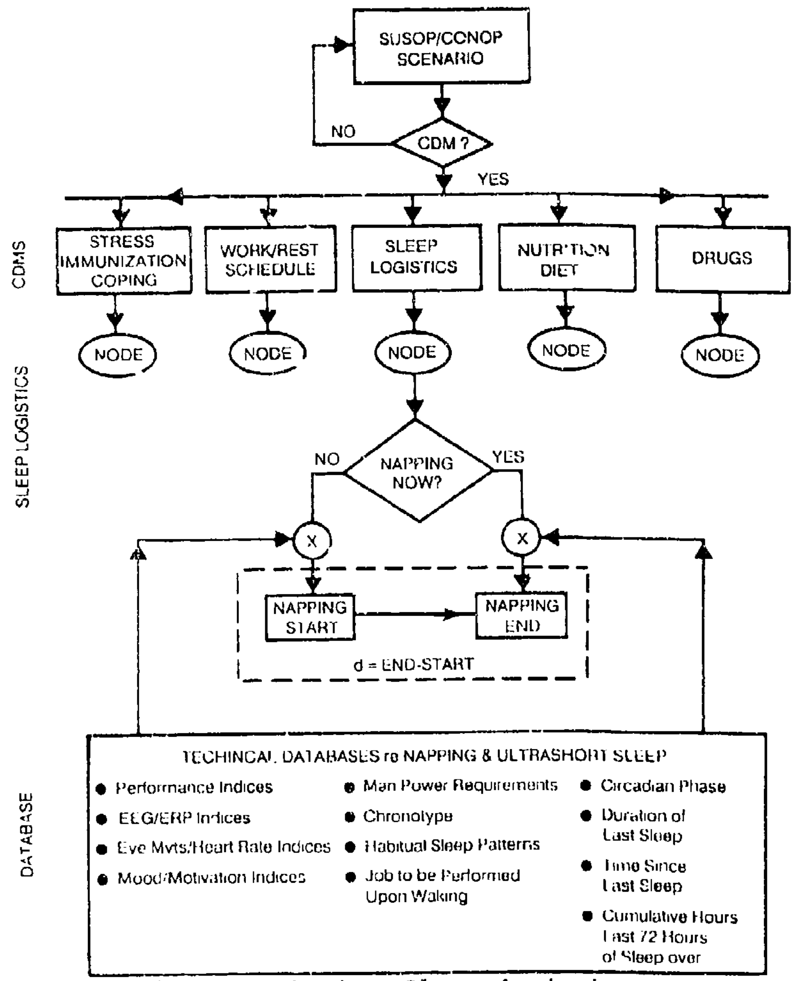

Figure 1. A flow diagram showing Sleep Logistics as one of the five measures to counteract performance degradation during sustained/continuous operations (SUSOP/CONOP). When a work schedule (scenario) interferes with regular sleep routine, sleep managers need to initiate one or more of counter degradation measures (CDM). Five CDMs are listed in this Figure (Stress Immunization, Work/Rest Schedule and others). The applications of Sleep Logistics consists of making an observation as to whether individuals are asleep or awake. If they are awake, a decision must be made as to when a nap is recommended; if asleep, when to wake them. The decision must be based on a technical database (boxed-in in this Figure) on napping and ultrashort sleep. X = Decision point for either napping to begin or to end. d = Napping duration.

Figure 1 lists some of the known technical databases with which sleep managers must be familiar. For example, if a group of workers is not napping, its group performance indices are not up to the pre-set standard, and they show signs of persistent excessive sleepiness, then sleep managers will advise them to start napping. The sleep managers also should know that there are enough workers at the work site to afford letting this group off for a nap. Further development of technical database is necessary just to make a simple, but critical, decision of: To nap or not to nap.

8.2. PERFORMANCE MODEL FOR ULTRASHORT SLEEP

Another responsibility of the sleep manager is to develop a performance model similar to a conceptual one given in Figure 2.

The X-axis shows a 4 day period of sustained operation. The Y-axis is in an arbitrary unit with an arbitrary threshold index value. Performance above the threshold value is regarded as being at an acceptable level of competence. Performance index below the threshold is of unacceptable quality. The X-axis represents a 4 day long period of continuous work. The solid line represents a hypothetical performance index during a sustained operation when sleep is not allowed across 4 days. The hypothetical performance index shows a prominent circadian rhythm superimposed on a linear decrease in performance index across 4 days. Although the solid line in Figure 2 is arbitrarily drawn, it follows very closely to a generalized performance curve based on data from studies of the effects of 72 hour total sleep deprivation performance (Thorne, Genser, Sing and Hegge, 1983).

In Figure 2, six naps were allowed by a sleep manager to counter against performance impairment due to sleep loss. During day 1, the performance index fell below the threshold due to circadian dip, and a sleep manager decided to permit a short nap, Nap 1. Expected recovery in performance index is shown in a broken line. The duration of the nap is shaded. Early in Day 2, the performance index (the broken line) again hit the threshold, so the sleep manager decided to interject another nap, Nap 2. During the same Day 2, the sleep manager observed another dip in performance to trigger Nap 3 which is much longer than Nap 1 or Nap 2. The nap duration depends on the sleep manager's experience with Technical Database (cf. Figure 1). Currently, very few facts are available to determine how long a nap period

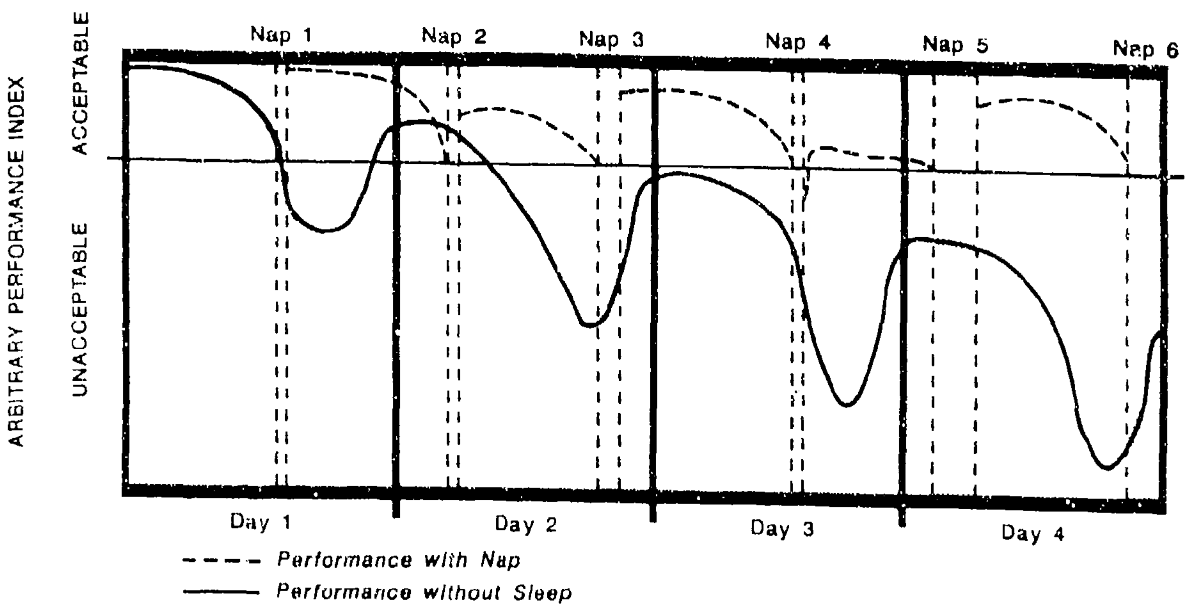

Figure 2: Hypothetical performance improvement due to adoption of 6 short nap periods during a 4 day long sustained/continuous operation. Without sleep, task performance decline in a predictable fashion down to the unacceptable level within 2 days (the solid line). With timely interjection of napping, the overall performance index remain at the acceptable level over 4 days of a continuous work period, overcoming the effects of sleep loss and circadian nadir on task performance (the broken line). Napping is imposed when the performance index fell below the arbitrarily set threshold value for the acceptable level. Napping ends when a sleep manager has judged that a nap was sufficiently long. See Text for details.

should be in order to achieve sufficient, enduring performance recovery. It is relatively easy to determine, using measures taken from brain waves (Pigeau, et al., (1987)) or performance indices, to conclude that sleep is needed immediately to maintain the level of performance. However, we have as yet to develop some on-line measures to indicate that a nap of sufficient duration was taken to warrant awakening.

In creating Figure 2, it was assumed that the science of sleep management has developed a performance model for ultrashort sleep. Figure 2 shows that the performance index of the sleep deprived becomes unacceptable after 1.5 days of continuous work. This means, without the ultrashort nap, the performance over the remaining 2.5 days (60 hours) is of unacceptable quality without any counter degradation measures (CDMs). Performance was maintained throughout the experiment taking naps 2 through 4. This means that naps totaling less than 10 hours, which are judiciously distributed during a sustained operation, regained about 50 odd hours of "useful time" towards a completion of the mission. The key utilities in developing this computerized behavioral model are how one decides when napping should start and when it should end.

The nap stop time is greatly influenced by non-psychophysiological factors such as work demands and manpower requirements. Napping will be topped when work demands require a larger number of workers on the job than are currently awake. The nap stop time also be estimated by knowing each individual's habitual sleep patterns, the duration of last sleep, the time since last sleep, the cumulative hours of sleep during the past 72 hours, the kind of job to be performed, and each individual's "chronotype" (morningness and eveningness). For sleep managers, a question of when to wake the sleeping workers and soldiers following a prolonged period of continuous work remains to be a difficult one. This is an area of research in the future.

9. DISCUSSION AND CONCLUSIONS

The sleep managers' task is to create a humane work schedule for irregular or prolonged work. Sleep managers should remember that most shift workers keep their work hours, not because it is good for them, but because it is good for the society. The least the science of sleep management can do for them is to make their work more bearable, safe, and productive by

proper sleep management as a part of the overall shift work planning and manpower allocation. Sleep managers should create new work ethics where yawning and sleeping at work sites are looked upon favorably.

In the search for sleep quantum, there appears to be a consensus that a period of 4.5-5.5 (average of 5) hours of continuous sleep per 24 hours would satisfy the daily requirement for core sleep, hence, maintaining a high level of job performance for an indefinite period of time. However, there seems to be no agreement among sleep researchers whether the 4.5-5.5 hours of sleep can be taken as a smaller packet, for example, of 10, 20 and 30 minutes of sleep. It is known that having many episodes of an extremely short 1 minute sleep all night long does not have power of recuperation. What is not resolved is a question of how long each sleep episode should be before it becomes, at least, behaviorally recuperative.

Another unresolved question is what are the mechanisms through which the ultrashort sleep loses recuperative power? As discussed previously, the sleep inefficiency of ultrashort sleep is due to the fact that one cannot fall asleep quickly during time periods which are allocated for sleeping. It is not known, however, whether the shortness of sleep, in itself, has reduced recuperative power. For example, if we let sleepers accumulate a total of 5 hours of sleep in 5 separate episodes of sleep by letting them continue sleeping until they have 1 hour of sleep, is this "fragmented sleep" less recuperative than sleep of 5 continuous hours? No definitive data are available. If a fragmented 5 hour sleep has far less recuperative power than a 5 hour continuous sleep, we could certainly conclude that the continuity of sleep itself plays a vital role in determining recuperative power.

There is another unresolved question about ultrashort sleep. As Bonnet (1986) and Magee et al (1987) noted in their studies, 1 minute sleep does not include slow wave sleep and REM sleep even after accumulation of many 1 minute long sleep episodes across the entire night. It seems that sleep is too short to include SWS and REM sleep and it is also too short to be recuperative. In contrast, when each sleep episode is 10 minute long, all night sleep includes almost one half of normal SWS and REM sleep, and sleep appears to be recuperative. Comparisons of the differences in sleep stages between 1 minute versus 10 minute sleep episodes in terms of power of recuperation might revive a familiar argument that the inclusions of SWS and REM

sleep are responsible for recuperation. However, Bonnet (1986) argues competently against invoking the sleep stages to explain recuperation, because there were no significant correlations between amount of SWS or REM sleep and performance recovery. Bonnet feels that the fact that one sleep episode was 10 minutes, another was 1 minute is the determining factor in recuperative power of sleep. Sleep stages have nothing to do with recuperation. More experimental evidence is, however, needed to resolve this issue of sleep stages versus duration of sleep episode in terms of the recuperative power.

Finally, the role of adaptation needs to be emphasized regarding ultrashort sleep schedules. Stampi's observations showed a relative ease of adaptation to ultrashort schedules, despite commonly held opinions to the contrary. The recuperative power of ultrashort sleep may partly depend on a degree of adaptation to the lifestyle involving needs for ultrashort sleep. A majority of research summarized in this paper does not provide the experimental subjects long enough adaptation time to the ultrashort sleep lifestyle. Hence, a decline of sleep efficiency under "short DAY" paradigm could have been reversed if the observation periods were much longer.

We used to feel that daytime naps, especially among the elderly, were undesirable events because they tended to degrade the quality of nocturnal sleep. Almost all sleep disorder patients show fragmented nocturnal sleep with daytime excessive sleepiness and poor performance; hence, fragmented sleep was regarded as poor, non-refreshing sleep to be avoided. The continuity theory of sleep predicts that only a period of uninterrupted and continuous sleep is recuperative. In this paper ultrashort sleep has been presented to be recuperative from daily fatigue and sleepiness. More data are needed to establish the conditions in which ultrashort sleep would benefit us in fulfilling daily responsibilities.

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Active sleep management is proposed to minimize degradation in job performance and to improve job safety in sustained operations. The key issues of sleep management are minimal sleep duration, time of day when the sleep is taken, the extent of prior sleep loss, the nature of jobs to be performed, and individual differences in sleep habits. This paper focuses on the questions of minimal sleep duration which is necessary to maintain an acceptable level of performance. The minimal sleep is found to be about 5 hours per 24 hours, and can be taken piecemeal. In this paper, ultrashort sleep on or near the work site is recommended as the means to maintain the high level of performance in sustained operations.

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